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Two new species of *Tamarixia* (Hymenoptera: Eulophidae) from Chile and Australia, established as biological control agents of invasive psyllids (Hemiptera: Calophyidae, Triozidae) in California

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Abstract

Tamarixia schina Zuparko **sp. nov.** and *T. dahlsteni* Zuparko **sp. nov.** are described. Both species have become established in California following their introductions from Chile and Australia, respectively, for control of invasive psyllids. *Tamarixia schina* is known from *Calophya schini* (Hemiptera: Calophyidae) on *Schinus molle* (Anacardiaceae) and *T. dahlsteni* from *Trioza eugeniae* (Hemiptera: Triozidae) on *Syzygium paniculatum* (Myrtaceae). The use of *Tamarixia* in biological control is discussed, and an annotated list of world species including distribution, hosts, and host plants, is provided. *Tetrastichus atamiensis* Ashmead is transferred to *Tamarixia* as *Tamarixia atamiensis* (Ashmead) **comb. n.**

Key words: Insecta, *Tamarixia schina*, *Tamarixia dahlsteni*, *Tamarixia radiata*, *Tamarixia dryi*, *Tamarixia leucaenae*, *Tamarixia atamiensis*, biocontrol

Introduction

The peppertree psyllid, *Calophya schini* Tuthill (Hemiptera: Calophyidae) was first discovered in California in 1984 after being accidentally introduced from South America (Downer *et al*. 1988; da Silva 1994; Dreistadt *et al*. 2004). It was originally reported in Long Beach, and subsequently spread through coastal regions of the state from San Francisco to San Diego. This species seems to only attack the California pepper tree, *Schinus molle* Linnaeus (Anacardiaceae), and does not attack the congeneric Brazilian pepper tree *S. terebinthifolius* Raddi, which is also extensively planted throughout the state. Damage is caused by the nymphal stage. Adults deposit their eggs on the fresh growing tips, and the nymphs settle and form deep pits which can deform and discolor leaves and cause distortion of twiglets and even disfigured trees (Fig. 1). In warmer climates, reproduction and all life stages can occur throughout the year (Dreistadt *et al*. 2004). *Calophya schini* had been considered a synonym of *Calophya rubra* (Blanchard) (e.g. Burckhardt 1988; da Silva 1994; Dreistadt *et al*. 2004), but was removed from synonymy and reinstated as a valid species by Burckhardt & Basset 2000.

The eugenia psyllid, *Trioza eugeniae* (Froggatt) (Hemiptera: Triozidae), was first detected in Inglewood, California in May 1988, becoming a major pest of Australian bush cherry or lilly pilly, *Syzygium paniculatum* Gaertner (Myrtaceae), in the coastal counties (Downer *et al*. 1991; Dahlsten *et al*. 1995). It had spread throughout coastal regions of southern California by the end of 1988, and reached northern California in early 1989. Small populations of the eugenia psyllid were found in Florida in 1993, but these populations were eradicated at that time and further colonies have not been found (Mead 1994). The eugenia psyllid is multivoltine, with three to five generations a year in California. As with the peppertree psyllid, adults oviposit into new growth, and the nymphs form pits on the surface of the leaf (Fig. 2) where they feed and develop (Dahlsten *et al*. 1995; Dreistadt *et al*. 2004). Leaves can be severely disfigured, reducing the ornamental value of the plant.

Classical biological control programs were instituted by workers from the Division of Biological Control, University of California, Berkeley, against both species. Foreign exploration work in South America resulted in the

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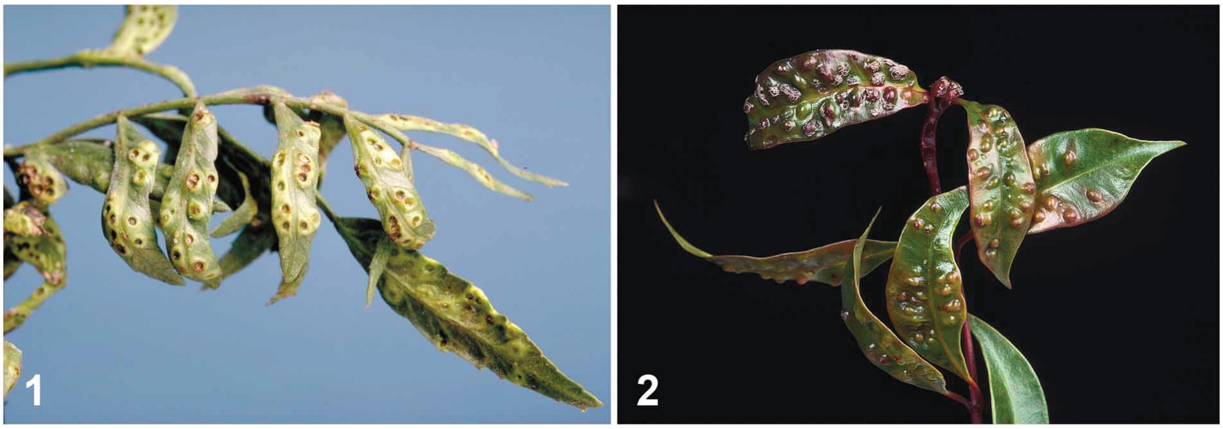
importation of a *Tamarixia* (Hymenoptera: Eulophidae: Tetrastichinae) species from Chile against *C. schina*. This parasitoid species was first introduced in 1987, and has resulted in substantial control (da Silva 1994). A recent integrated pest management guide indicated that in the warmer parts of the state, chemical control measures were not necessary, and the only control measures needed were the conservation of parasitoids (Dreistadt *et al*. 2004). In cooler areas, biological control might need to be augmented with the use of systemic insecticides.

In 1991, foreign exploration work in Australia was initiated and resulted in the importation of another *Tamarixia* species against *T. eugeniae*. The parasitoid quickly established, but provided only partial biological control of this pest; however the psyllid can be managed at reasonable levels with a combination of parasitoids and selective pruning (Dahlsten *et al.* 1995; Dreistadt *et al*. 2004).

The purpose of this paper is to describe the two *Tamarixia* species introduced into California, and to summarize data on the distribution, hosts, and biocontrol applications for all described *Tamarixia* species.



FIGURES 1, 2. 1. Damage caused by *Calophya schini* on *Schinus molle*. 2. Damage caused by *Trioza eugeniae* on *Syzygium paniculatum*. Photos by Jack Kelly Clark, courtesy University of California Statewide IPM Program. Copyrighted by the Regents of the University of California.

Material and methods

Terminology follows LaSalle (1994) and Gibson *et al*. (1997). Observations and measurements were made using a Nikon dissecting microscope (top magnification of 63x) with a 100-division linear scale micrometer.

Distribution records list the **COUNTRY**, STATE (for Australia, Mexico & USA) or REGION (for Chile), *county* (for USA) or *province* (for Chile), and locality.

Acronyms used are as follows: ANIC, Australian National Insect Collection, CSIRO Ecosystem Sciences, Canberra, Australia; BMNH, The Natural History Museum, London, UK; CAS, California Academy of Sciences, San Francisco, CA, USA; CIIDIR-IPN, Centro Interdisciplinario para el Desarrollo Regional, Unidad Durango, Instituto Politécnico Nacional, Durango, Estado Durango, Mexico; EMEC, Essig Museum of Entomology, University of California, Berkeley, CA, USA; MNHM, Museo Nacional de Historia Natural, Santiago, Chile; QMB, Queensland Museum, Brisbane, Queensland, Australia; UCD, Bohart Museum, University of California, Davis, CA, USA; UCR, Entomological Research Museum, University of California, Riverside, CA, USA; UNAM, Universidad Nacional Autonoma de Mexico, Mexico City, Mexico D.F., Mexico; USNM, National Museum of Natural History, Smithsonian Institution, Washington, DC, USA.

Tamarixia Mercet, 1924

Type species: *Tamarixia bicolor* Mercet, 1924 (original designation)

Diagnostic characters. *Tamarixia* possesses two apomorphic characters that are unique within the Tetrastichinae: males have exceptionally long genitalia, and the anterior margin of the female hypopygium is almost straight

(which may be hidden under the preceding sternite and is not easily visible in undissected specimens). Specimens of *Tamarixia* can also generally be distinguished by a combination of characters: fore wing with a single seta on the dorsal surface of the submarginal vein, propodeum without a Y-shaped carina as seen in *Tetrastichus* (although see description of *Tamarixia dahlsteni*), midlobe of mesoscutum with 2 pairs of long, semi-erect setae that are about equal in length (Figs 14, 15) (although some specimens of *T. dahlsteni* have three pairs) (Graham 1991; LaSalle 1994). An additional diagnostic character is that the toruli are closer to eye margin than to each other (Figs 6, 13). Species are generally shiny black, but may have yellow markings on the gaster and/or head.

Identification. *Tamarixia* contains species once treated as belonging to the *pubescens* group of the genus *Tetrastichus* (Graham 1961; Domenichini 1966, 1967). The species group was subsequently treated as a subgenus within *Tetrastichus* by Kostjukov (1977, 1978), but has since been treated as a genus by most authors (Graham 1987, 1991; Bouček 1988a; LaSalle 1994; Kostjukov, 1995, 1996, 2000; Schauff *et al*. 1997; Narendran 2007).

Generic keys that distinguish *Tamarixia* from other tetrastichine genera are available for Australasia (Bouček 1988a), North America (LaSalle 1994; Schauff *et al*. 1997), Europe (Graham 1987, 1991) and India (Narendran 2007). Keys to *Tamarixia* species are available for Europe (Graham 1991), European part of the USSR (Kostjukov 1978: couplets 68–87 in key to *Tetrastichus*), Far eastern Russia (Kostjukov 1995, 2000), India (Narendran 2007) and North America (Burks 1943, couplet 24 in the key to species of the genus *Tetrastichus*, treating only the two species). A list of the 47 described *Tamarixia* species, with host and distributional information, is given in Table 1.

TABLE 1. Annotated list of species of *Tamarixia.* See Noyes (2003) for further information on taxonomic history and synonymy. Classification of psyllid hosts follows Burckhardt (2005). Host information mainly taken from Noyes (2003), and in some cases updated following Burckhardt (pers. comm.) and Burckhardt & Lauterer (1997) for *Bactericera*.

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actis (Walker 1839)
Distribution. Europe: Czech Republic, France, Germany, Hungary, Ireland, England. Macaronesia: Azores, Canary Islands.
Hosts. Psyllidae, Strophingiinae: *Strophingia cinereae* Hodkinson, *Strophingia ericae* (Curtis).
Host plants. Ericaceae: *Calluna vulgaris* (Linnaeus), *Erica cinerea* Linnaeus, *Erica scoparia* Linnaeus.

***akkumica* (Kostjukov 1978)**
Distribution. Asia: Kazakhstan.

***arboreae* (Graham 1979)**
Distribution. Macaronesia: Madeira Islands.
Hosts. Psyllidae, Strophingiinae: *Strophingia arborea* Loginova, *Strophingia fallax* Loginova.
Host plants. Ericaceae: *Erica arborea* Linnaeus, *Erica scoparia* Linnaeus.

***asiatica* Kostjukov 1996**
Distribution. Asia: Kazakhstan.

atamiensis* (Ashmead 1904). New combination from *Tetrastichus
Tetrastichus atamiensis Ashmead, 1904: 162. Holotype ♀, Japan, Atami. USNM Type 7206 [examined, digital image].
Distribution: Asia: Japan.

bermius* (Walker 1848) = *upis

***bicolor* Mercet 1924**
Distribution. Europe: Bulgaria, Spain. Asia: Pakistan.
Hosts. Triozidae: *Trioza chenopodii* Reuter.
Host plants. Chenopodiaceae: *Chenopodium album* Linnaeus.

***brovni* Kostjukov 2000**
Distribution. Asia: Russia (Primor'ye Kray).

***caillardiae* (Kostjukov 1978)**
Distribution. Asia: Kazakhstan.
Hosts. Psyllidae, Aphalarinae: *Caillardia notata* Loginova.
Host plants. Amaranthaceae: *Haloxylon* sp.

callunae (Erdös 1969) = *actis*

***cometes* (Girault 1915)**
Distribution. Australia (Northern Territory).

***dahlsteni* Zuparko, sp. nov.**
Distribution. Australia (New South Wales, Queensland, Western Australia, Victoria).
Hosts. Triozidae: *Trioza eugeniae.*
Host plants. Myrtaceae: *Syzygium paniculatum.*
Biological control. Imported into USA: California for the biological control of *Trioza eugeniae*.

***dhetysaicus* Kostjukov 1996**
Distribution. Asia: Kazakhstan.

***dryi* (Waterston 1922)**
Distribution. Africa: Kenya, South Africa, Swaziland, Zimbabwe.
Hosts. Triozidae: *Trioza erytreae* (Del Guercio).
Host plants. Rutaceae: *Citrus* spp.
Biological control. Imported into Réunion, Mauritius for the biological control of *Trioza erytreae.*

***dwivarnus* Narendran 2007**
Distribution. Asia: Sri Lanka.

***dyra* (Burks 1943)**
Distribution. North America: USA (Colorado, Montana, Wyoming).
Hosts. Psyllidae, Aphalarinae: *Aphalara curta* (Caldwell); Triozidae: *Trioza* sp.
Host plants. Rutaceae: *Citrus* spp.; Apiaceae: *Angelica* sp.; Salicaceae: *Salix* sp.; Ranunculaceae: *Thalictrum* sp.

***flavicoxae* Kostjukov 2000**
Distribution. Asia: Russia (Primor'ye Kray).

***flavigaster* (Brothers & Moran 1969)**
Distribution. Africa: South Africa.
Hosts. Psyllidae, Rhinocolinae: *Moraniella calodendri* (Moran).
Host plants. Rutaceae: *Calodendrum capense* (Linnaeus filius).

***flaviventris* (Kostjukov 1978)**
Distribution. Asia: Kazakhstan, Tajikistan.

***girishi* Narendran 2007**
Distribution. Asia: India (Kerala).

***hanca* Kostjukov 2000**
Distribution. Asia: Russia (Primor'ye Kray).

***klarisae* Kostjukov 1996**
Distribution. Asia: Kazakhstan.

***leptothrix* Graham 1991**
Distribution. Europe: Czechoslovakia, Hungary, Ireland, Italy, England, Yugoslavia.
Host plants. Salicaceae: *Salix alba* Linnaeus, *Salix cinerea* Linnaeus, *Salix fragilis* Linnaeus.

***leucaenae* Bouček 1988**
Distribution. North America: USA (Florida). Central America and Caribbean: Mexico, Trinidad & Tobago.
Hosts. Psyllidae, Ciriacreminae: *Heteropsylla cubana.*
Host plants. Rutaceae: *Citrus* spp.; Fabaceae: *Leucaena* sp., *Leucaena leucocephala* (Lamarck).
Biological control. Imported into Africa and Asia for the biological control of *Heteropsylla cubana.*

***meteroa* (Girault 1915)**
Distribution. Australia (Queensland).

***monesus* (Walker 1839)**

Distribution. Europe: Czech Republic, England, France, Germany, Hungary, Ireland, Italy, Slovakia, Slovenia, Sweden, Yugoslavia. Asia: Kazakhstan, Moldova, Russia (Astrakhanskaya Oblast).

***newelskoyi* (Kostjukov 1990)**

Distribution. Asia: Russia (Yevreyskaya Oblast).

***nocturna* Kostjukov 2000**

Distribution. Asia: Russia (Primor'ye Kray).

obscuratus* (André 1878) = *pronomus

***orientalis* Khan, Agnihotri & Sushil 2005**

Distribution. Asia: India (Uttaranchal).

Hosts. Agromyzidae: Unspecified species. NOTE: This is the only record of a species of *Tamarixia* from an agromyzid, and indeed from a non-Hemipteran. It should be treated as doubtful without subsequent confirmation.

Host plants. Asteraceae: *Helianthus* sp.

orsillus* (Walker 1839) = *upis

***pallicornis* (Walker 1872)**

Distribution. Macaronesia: Madeira Islands.

pallicornis* (Thomson 1878) = *monesus

pallidicornis* (Dalla Torre 1898) = *monesus

pamyles* (Walker 1839) = *pronomus

***poddubnyi* (Kostjukov 1978)**

Distribution. Asia: Moldova, Uzbekistan, China (**new record**- NingXia, Yinchuan, Gaojiazha, 22 June 2010, coll. C.D. Zhu, on *Eleagnus angustifolia* Linnaeus).

Hosts. Triozidae: *Trioza magnisetosa* Loginova; Aphididae: *Capitophorus hippophaes* (Walker).

Host plants. Elaeagnaceae: *Elaeagnus* sp., *Elaeagnus orientalis* Linnaeus, *Eleagnus angustifolia* (**new record**).

***pojarkovi* (Kostjukov 1990)**

Distribution. Asia: Russia (Primor'ye Kray).

***pookodica* Narendran 2007**

Distribution. Asia: India (Kerala).

***pronomus* (Walker 1839)**

Distribution. Europe: Czech Republic, England, France, Germany, Greece, Hungary, Ireland, Italy, Norway, Portugal, Sweden. Macaronesia: Canary Islands, Madeira Islands.

Hosts. Triozidae: *Bactericera kratochvili* Vondracek, *Trioza apicalis* Förster, *Trioza centranthi* (Vallot), *Trioza urticae* (Linnaeus).

Host plants. Valerianaceae: *Centranthus angustifolius* (Miller).

***przewalskii* (Kostjukov 1990)**

Distribution. Asia: Russia (Yevreyskaya Oblast).

***pubescens* (Nees 1834)**

Distribution. Europe: Czech Republic, England, Germany, Hungary, Italy, Slovakia, Yugoslavia.

Hosts: Triozidae. *Trioza remota* Förster.

pygmaea* (Erdös 1954) = *pygmaeola

***pygmaeola* (Erdös 1958)**

Distribution. Europe: France, Hungary, Yugoslavia.

Hosts. Triozidae: *Trioza rumicis* Löw.

Host plants. Polygonaceae: *Rumex scutatus* Linnaeus.

***radiata* (Waterston 1922)**

Distribution. Asia: India, Pakistan.

Hosts. Psyllidae, Diaphorininae: *Diaphorina citri*; Psyllidae, Aphalaroidinae: *Pallipsylla hyalina* (Mathur); Triozidae: *Trioza erytreae*, *Trioza* sp.

Host plants. Fabaceae: *Albizia lebbeck* (Linnaeus); Rutaceae: *Citrus* spp., *Murraya paniculata* (Linnaeus).

Biological control. Imported into Réunion, India, Saudi Arabia, Mauritius, Nepal, Taiwan, China, Indonesia, Malaysia, Thailand, Vietnam, USA (Florida, Texas), Mexico, Brazil, Argentina, Guadeloupe, Puerto Rico for the biological control of *Diaphorina citri*.

***rudolfae* (Kostjukov 1978)**

Distribution. Asia: Kazakhstan.

***schina* Zuparko, sp. nov.**

Distribution. South America: Chile.

Hosts. Calophyidae: *Calophya schini.*

Host plants. Anacardiaceae: *Schinus molle.*

Biological control. Imported into USA (California) for the biological control of *Calophya schini*. Also present in Mexico, presumably as spread of the California introduction.

***sheebae* Narendran 2005**

Distribution. Asia: India (Kerala).

Host plants. Combretaceae: *Terminalia arjuna* Roxburgh.

***stelleri* (Kostjukov 1990)**

Distribution. Asia: Russia (Primor'ye Kray).

tamaricis* (Domenichini 1967) = *bicolor

***tremblayi* (Domenichini 1965)**

Distribution. Europe: Czechoslovakia, Italy, United Kingdom.

Hosts. Triozidae: *Bactericera tremblayi* (Wagner).

Host plants. Alliaceae: *Allium cepa* Linnaeus.

***triozae* (Burks 1943)**

Distribution. USA (Arizona, California, Colorado, Idaho, Kansas, Montana, Nebraska, New Mexico, Texas, Washington). NOTE: Herting (1972) recorded this species from Italy, and Chazeau (1987) reported it from New Caledonia on *Heteropsylla cubana* on *Leucaena leucocephala*. Because *T. triozae* is otherwise known only from the Nearctic region, we suspect these records are misidentifications.

Hosts. Calophyidae: *Calophya californica* Schwarz, *Calophya nigrella* Jensen, *Calophya nigripennis* Riley, *Calophya triozomima* Schwarz; Psyllidae: *Ceanothia ceanothi* (Crawford), *Euglyptoneura minuta* (Crawford), *Euphalerus vermiculosus* Crawford, *Pexopsylla cercocarpi* Jensen; Triozidae: *Bactericera cockerelli* (Sulc), *Bactericera minuta* (Crawford), *Bactericera nigricornis* (Förster), *Trioza albifrons* Crawford, *Trioza beameri* Tuthill.

Host plants. Rosaceae: *Amelanchier* sp.; Solanaceae: *Solanum tuberosum* Linnaeus.

***tschirikovi* (Kostjukov 1990)**

Distribution. Asia: Russia (Yevreyskaya Oblast).

***turundaevskayae* (Kostjukov 1978)**

Distribution. Asia: Kazakhstan.

***upis* (Walker 1839)**

Distribution. Europe: Czech Republic, England, France, Italy, Slovakia, Sweden, Moldova, Russia (Moscow Oblast, St. Petersberg). Macaronesia: Madeira Islands.

Hosts. Triozidae: *Bactericera femoralis* (Förster), *Trioza urticae.*

Host plants. Rosaceae: *Alchemilla vulgaris* Linnaeus; Urticaceae: *Urtica* sp.

***vinokurovi* Kostjukov 1995**

Distribution. Asia: Russia (Primor'ye Kray).

***yoorica* Narendran 2007**

Distribution. Asia: India (Kerala).

Distribution. *Tamarixia* is a cosmopolitan genus, with most of its 47 described species from the Palearctic and Oriental regions (Table 1). Because the greatest diversity of Psylloidea occurs in the southern tropics (Hodkinson 1984), the number of known *Tamarixia* species will undoubtedly increase as the fauna from Africa, Australia and South America becomes better characterized. During the course of this study, specimens have been examined that represent quite a few new species from North America (California, Florida), South America (Brazil, Chile), and Australia. It is clear that further collecting and rearing of psyllids will greatly expand the known fauna of this genus.

Biology. Species of *Tamarixia* are primary parasitoids of psyllids (Graham 1987, 1991; Bouček 1988a, 1988b; LaSalle 1994; Noyes 2003). However, aphids can also serve as hosts for *Tamarixia* species. In his description of *T. poddubnyi*, Kostjukov (1978) recorded it from the aphid *Capitophorus hippophaes* (Walker), and an undescribed *Tamarixia* species in EMEC has the label data: California: Los Angeles County, Highway 138, 6 miles east of Gorman, 1 June 1961, J.C. Hall, reared from *Aphis gossypii* [Glover] on *Solanum elaeagnifolium* [Cavanilles]. Further collecting will be required to understand just how frequent the use is of non-psyllid hosts. A record of *T. orientalis* Khan, Agnihotri & Sushil from an agromyzid (Table 1) should be treated as doubtful without subsequent confirmation.

Most records list *Tamarixia* species as ectoparasitoids, however *T. upis* (Walker) has been recorded as an endoparasitoid (Noyes 2003).

Descriptions of new species

Tamarixia schina Zuparko, sp. nov.

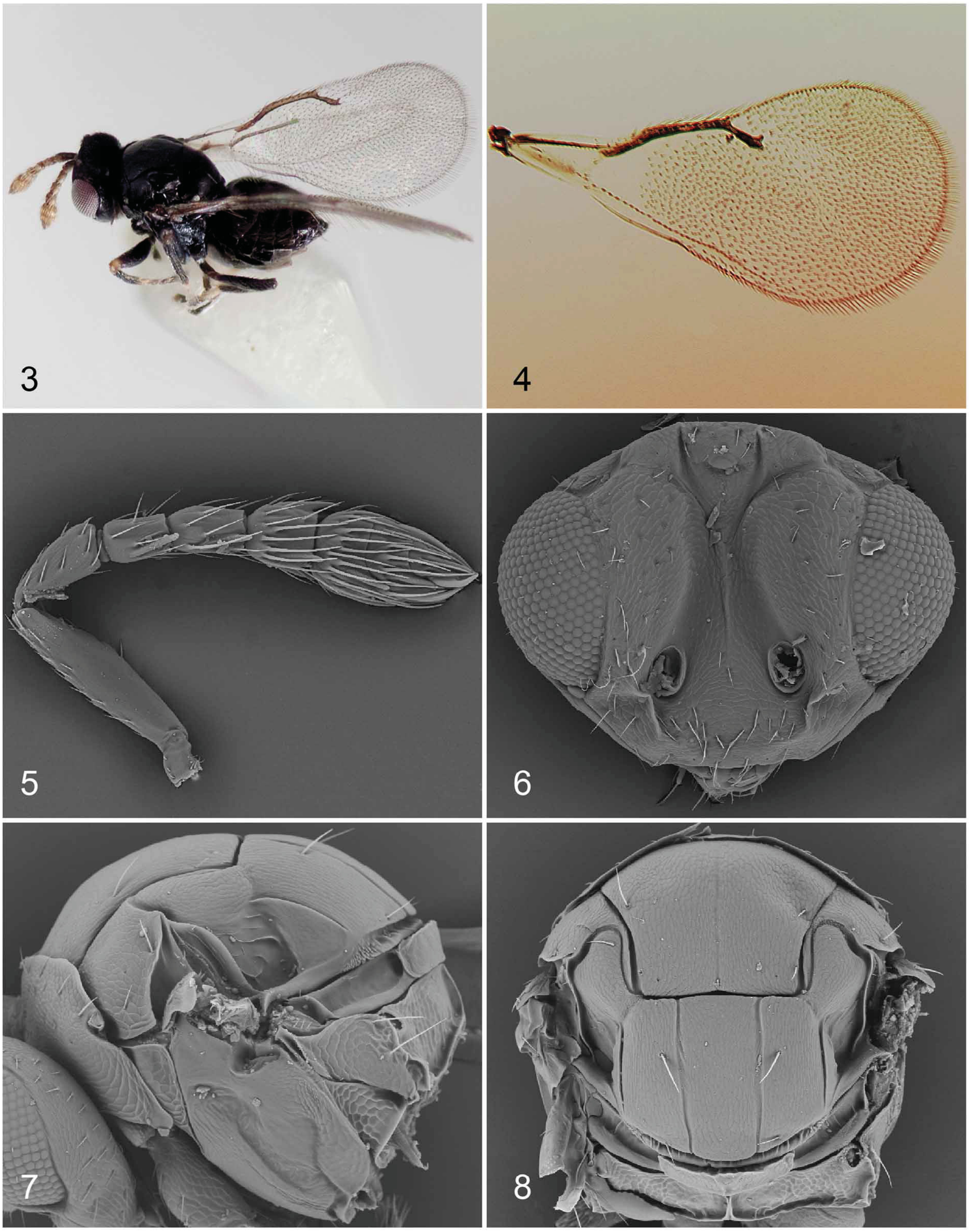
(Figs 3–8)

Diagnosis. Individuals of *T. schina* are distinguished from other *Tamarixia* species in North America by a distinct shape of the mesosoma and coloration. In profile, the mesosoma is as high as long, and the plane marked by the dorsellum and propodeum is steeply inclined, appearing almost perpendicular to the longitudinal body axis (Fig. 7), whereas in other species this plane is less inclined (Fig. 14), at an angle much less than 45º to the dorsal plane of the mesosoma. *Tamarixia schina* is an extremely dark species (Fig. 3). Females have the antennal scape and all legs black, with only a faint lightening at the apices of the femora and tibiae, whereas females of other species have much more extensive white or yellow markings. Males closely resemble those of *T. triozae* (Burks 1943) in coloration, but the former have darker fore femora and less elongated funicle segments.

Description. FEMALE. Body length: 0.75–1.04 mm; wingspan: 2.07–2.94 mm. Shiny black, some specimens with brown areas; eye dark red; scape black except yellow-brown apically; pedicel dark basally, yellow-brown apically extending basally on ventral surface; flagellar segments light brown, slightly darker dorsally; club light brown; legs dark, basal and distal apices of fore femur and tibia narrowly lightened, less distinctly so on mid- and hind femora and tibiae; tarsus yellow basally, darkening apically. Wings hyaline, veins brown. Relative measurements: head (collapsed in all examined specimens) width: 24, length: 8, height: 19; eye length: 7, height: 12; malar space: 5; antennal segments (length:width) scape, including radicle: (10:2), pedicel: (4.5:2.5), F1: (3:2), F2: (3:2), F3: (3:3), club: (6:4); mesosoma length: 26, width at tegulae: 23, height: 22; width of scutellar median area: 5, sublateral areas: 4; fore wing length: 65, maximum width: 32, costal cell length: 21, marginal vein length: 12, stigmal vein length: 6; hind wing length: 51, width at hamuli: 10; gaster length: 27, width: 20. Antenna inserted level with lower edge of eye, scape not quite reaching anterior ocellus. Eye apparently bare. Mesoscutum with median line visible over posterior 80%; 2 pairs of adnotaular setae. Head and most of mesosoma reticulate, but dorsellum smooth with only faint markings. Propodeum with distinct median carina, callus with 2 setae, spiracle round, almost touching anterior edge of propodeum. Ratio of median lengths of dorsellum:propodeum = 3:5. In profile, dorsellum flat, posterior border of scutellum, dorsellum, and propodeum almost in same plane, inclined 60–90o from the longitudinal axis of the body. Fore wing apically rounded, almost truncate; stigmal vein wider apically than basally, not appearing as constricted as in *T. dahlsteni*, with distinct uncus; postmarginal vein absent; speculum extending from point posterior to parastigma to point about midway along marginal vein. Hind wing apically acute, vein extending to hamuli, about 0.5x wing length; longest length of fringe about 0.5x wing width.

MALE. Body length: 0.73–0.89 mm; wing span: 2.00–2.57 mm. As female, except antenna darker, proximal and distal apical yellow bands on femora and tibiae slightly broader and brighter, tarsi lighter, occasionally tibiae and tarsi (except ultimate segment) all yellow, and plane delimited by posterior section of scutellum, dorsellum and

propodeum inclined less than 60º from longitudinal axis of the body. Relative measurements of antennal segments (length:width): scape, including radicle: (11:3), pedicel: (4:3), F1: (4:3.5), F2: (5:3.5), F3: (5:3), F4: (5:3), C1: (4:2.5), C2: (4:2.5), C3: (3:2). Segments F2 to C3 basally with long setae, about 2–4x widest width of segment. Apex of forewing almost truncate. Speculum reduced, about 0.5x that of the female. Gaster oblong, length about 2x width. Genitalia with digitus long and narrow, length about 8–10x width, tipped with a hook curving laterad; paramere with apical stylus and slightly shorter than digitus; aedeagus length 9–10x basal width, about 2.3x length of digitus, with apex acute.



FIGURES 3–8. *Tamarixia schina,* female. 3. Habitus. 4. Forewing. 5. Antenna. 6. Head, frontal view. 7. Mesosoma, lateral view. 8. Mesosoma, dorsal view.

Distribution. Chile (Coquimbo [Elqui], Valparaiso [Valparaiso, San Felipe de Acancagua], Santiago Metropolitan Region [Santiago], O'Higgins [Cardenal Caro, Cachapoal]), USA (coastal area of California), Mexico (Estado Mexico).

Hosts. Known only from *Calophya schini*, a primary ectoparasitoid of late-instar nymphs.

Type material. Holotype, ♀: **CHILE**. COQUIMBO: *Elqui*: 10 km W of Vicuna on road to La Serena, 500 m, 8 Apr 1987, L. E. Caltagirone, *Calophya schini* on *Schinus molle*, Quarantine #87-7.3; deposited: EMEC. Paratypes (73 total): **CHILE**. Same data as holotype, 1 ♀, 1 ♂ (EMEC); COQUIMBO: *Elqui*: Vicuna, 600 m, 8 Apr 1987, L. E. Caltagirone, *C. schini* on *S. molle*, Quarantine #87-7.1, 1 ♂ (MNHN). VALPARAISO: *San Felipe de Acancagua* and *Valpariso*: Panquehue–Puchuncavi, 9 Mar 1987, L. E. Caltagirone, *C. schini* on *S. molle*, Quarantine #87-5, 1 ♀, 1 ♂ (MNHN, USNM). Lab culture, ex psyllid on leaves of *S. molle*, 5 May 1987 (originating from Quarantine #87-7), 1 ♀ (EMEC). Lab culture F3 adults, ex. *C. rubra* on leaves of *S. molle*, emerged 22 Jun 1988 (originating from O'HIGGINS: *Cardenal Caro*: Marchihue, L.E. Caltagirone, Quarantine #87-3: 20–22), 1 ♂ (USNM). **MEXICO**. MEXICO: Texcoco & Chapingo: Apr and May 1998, R. Alvarez-Zagoya, reared from 3rd–5th instar *C. schini*, 20 ♀ (EMEC, CIIDIR-IPN, UNAM). **USA**. CALIFORNIA. *Alameda* Co.: Berkeley, 6 Aug 1994, R.L. Zuparko, on *Schinus* sp., 1 ♀ (EMEC); Berkeley, corner of Peralta & Vincente Ave., 26 Oct 2010, R.L. Zuparko, swept from *Schinus molle,* N37°53.610 W122°17.140, 4 ♀ (ANIC); *Santa Clara Co*.: Sunnyvale, Hwy 237/Lawrence Expressway Interchange, R.L. Tassan, ex. *Callophya schini* on *Schinus molle*, coll. 27 May 1988, emerged 15-30 Jun 1988, 19 ♀, 1 ♂ (ANIC, BMNH, CAS, EMEC, MNHN, USNM, UCD, UCR); lab culture of *C. schini* on *Schinus* sp., Sept 1989, 21 ♀ (BMNH, CAS, EMEC, MNHN, USNM, UCD, UCR).

Etymology. The species name is derived from its only known host species, *Calophya schini*.

Discussion. There is a contradiction in the label data of the paratypes from Santa Clara County (USA: California), which specifies the city of Milpitas. However, the intersection of Highway 237 with the Lawrence Expressway is actually within the city limits of Sunnyvale, about four miles west of Milpitas.

La Salle (1994) mentioned several undescribed *Tamarixia* species from South America; however, this is the first species to be described from that continent. It is found in Mexico, probably as an adventitious importation, through plantings of *Schinus* species infested with *C. schina*. In California, *T. schina* appears to be deuterotokous—males are rare, but sexually functional (K.S. Hagen, personal communication).

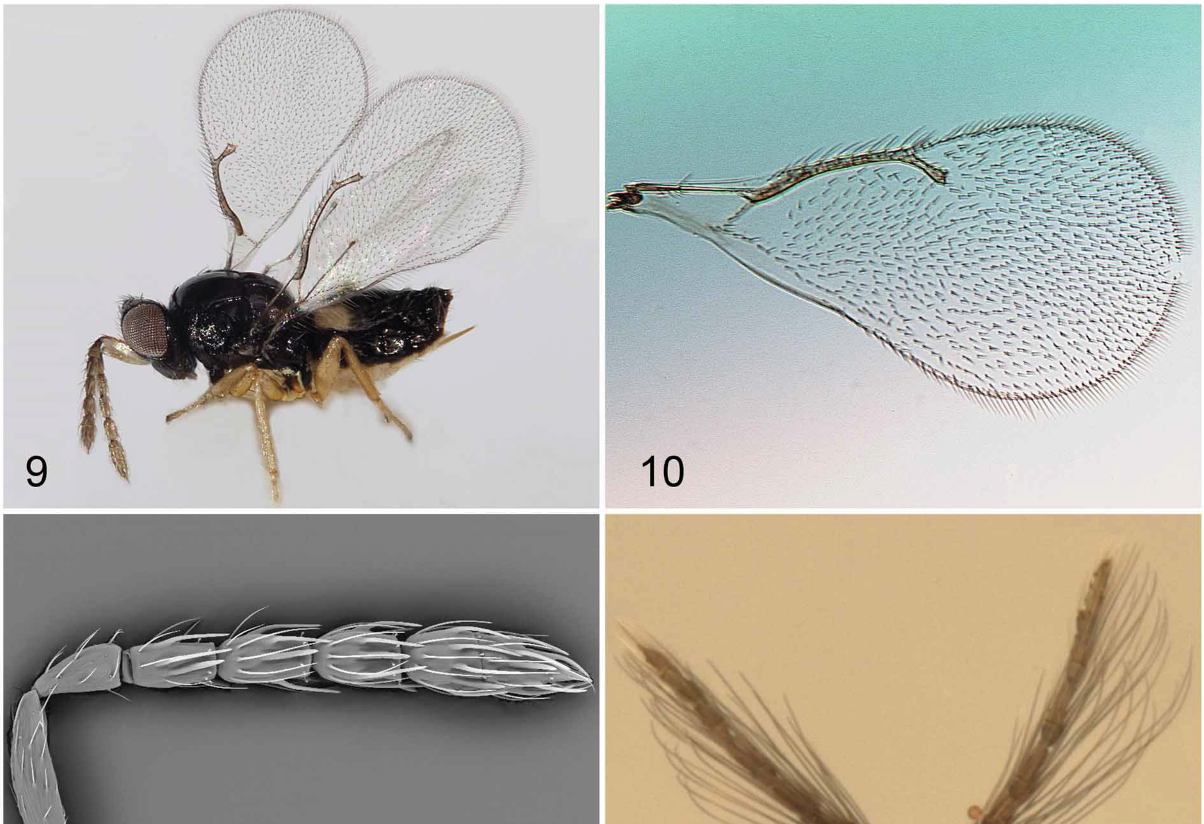
Tamarixia dahlsteni Zuparko, sp. nov.

(Figs 9–16)

Diagnosis. Female *T. dahlsteni* are easily distinguished from all other described *Tamarixia* species from North America by an extensively yellow gaster (rather than completely dark). The entire ventral surface of the gaster is yellow, and dorsally the yellow extends to or slightly beyond the apex of the 2nd gastral tergite (Fig. 9). There is an undescribed species of *Tamarixia* from Florida (ex. *Ceropsylla sideroxylii* on *Sideroxylon foetidissimum* Jacquin, EMEC, ANIC) that also has yellow markings on the gaster, but in that species the dorsal yellow coloration extends to the apex of the gaster, although it may be interrupted by one or more transverse brown stripes. Additionally, *T. dahlsteni* has a distinct paraspiracular carina medial to the propodeal spiracle that is posteriorly bifurcate (Figs 15, 16), similar to that seen in species of *Tetrastichus*. This is the only species of *Tamarixia* in North America with such a carina. Males of *T. dahlsteni* are less distinctive, but are separable from those of other *Tamarixia* species by a combination of a posteriorly bifurcate paraspiracular carina, forewing with a wide speculum, 3rd and 4th funicle segments 2.0x or longer than wide, and fore femur distinctly lighter than the hind femur.

Description. FEMALE. Body length: 0.87–1.25 mm; wingspan: 2.44–3.24 mm. Shiny black; eye dark red, ocelli bright red; scape yellow-brown, pedicel and flagellar segments light brown, darkened at base of each segment, markedly more so dorsally, club light brown; legs yellow, hind legs sometimes slightly darker, fore and hind coxae concolorous with body, the latter yellow apically, ultimate tarsal segment darkened apically; gaster with basal yellow spot extending about 0.5x length dorsally and entire length ventrally. Wing hyaline, veins brown. Relative measurements: head (slightly collapsed) width: 32, length: 12, height: 24; width of frons: 17, OOL: 4, POL: 9; eye length: 12, width: 14; malar space: 7; antennal segments (length:width): scape, including radicle: (13:3), pedicel: (5:2.5), F1: (5:3), F2: (5:2.5), F3: (5:2.5), club, including spicule: (11:3.5); mesosoma length: 34, width at tegulae: 28, height: 25; width of scutellar median area: 5, sublateral areas: 5; gaster length: 26, width: 23.5; fore

wing length: 80, width: 37; length costal cell: 20, marginal vein: 17, stigmal vein: 7; hind wing length: 62, width: 11. Antenna inserted slightly above lower level of eye, scape reaching anterior ocellus. Eye with short hairs. Mesoscutum with median line complete, but less distinct anteriorly, and 2 or 3 pairs of adnotaular setae. Head and mesosoma reticulate, except propodeum more rugose. Propodeum with distinct median carina, callus moderately developed with 2 setae, spiracle elongated, almost touching anterior edge of propodeum. Ratio of median lengths of dorsellum:propodeum = 3:4. In profile, posterior portion of scutellum, dorsellum and propodeum in the same plane, inclined about 50o from longitudinal axis of the body. Fore wing apically rounded, almost truncate; stigmal vein basally appearing markedly constricted, expanding apically and uncus present but less protuberant than in *T. schina*; postmarginal vein absent; speculum extending from point posterior to parastigma diagonally apically and anteriorly to marginal vein, narrow hairless band posterior to marginal vein and basal portion of stigmal vein. Hind wing apically acute, vein extending to hamuli, about 0.5x wing length; longest length of fringe about 0.5x wing width.



FIGURES 9–12. *Tamarixia dahlsteni*. 9. Habitus, female. 10. Forewing, female. 11. Antenna, female. 12. Head and antennae, male.

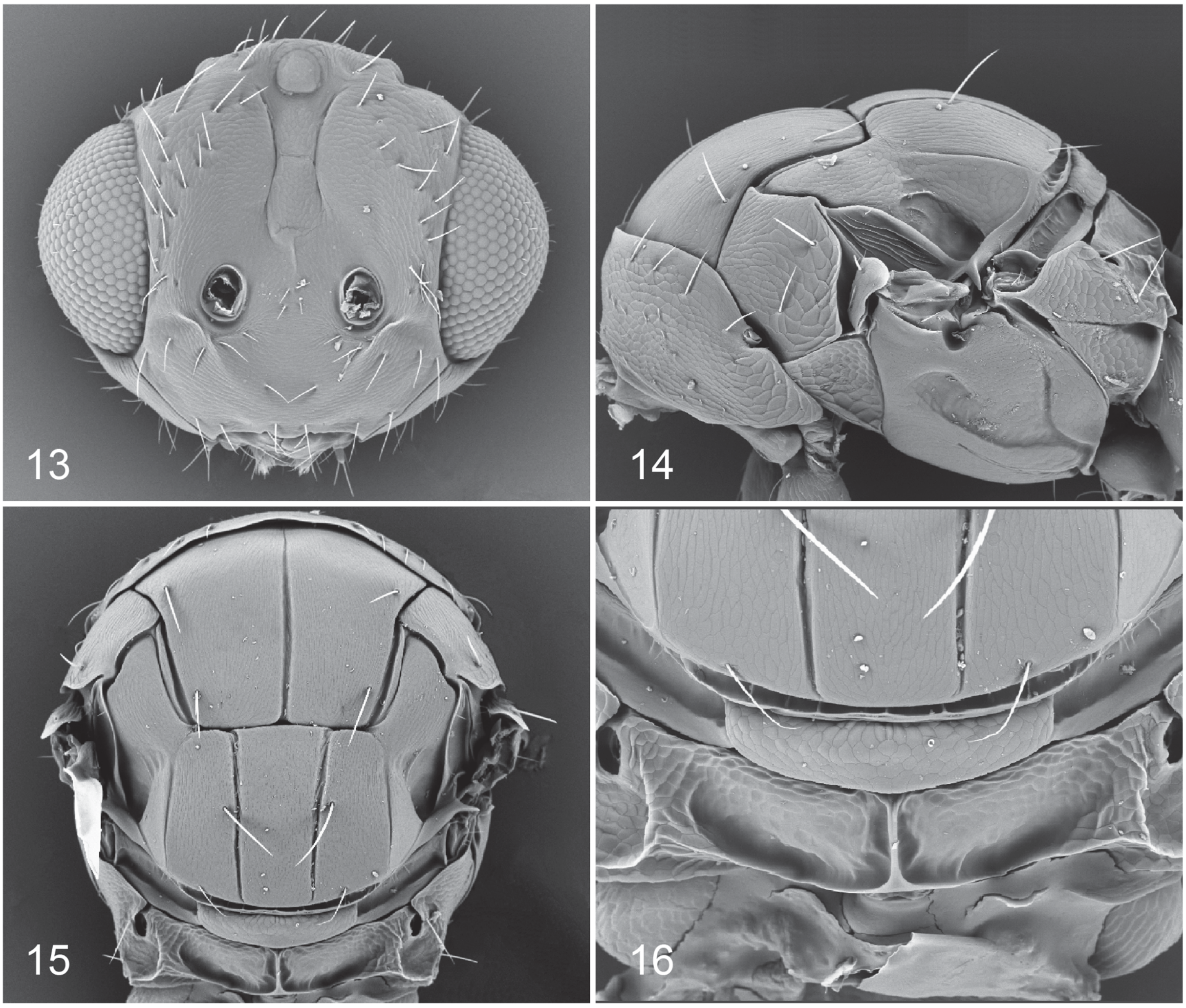
MALE. Body length: 0.70–1.20 mm; wing span: 1.80–2.94 mm. As female, except antenna brown with darker dorsal infuscations on scape and pedicel, and occasionally on F2–F4, F1–C1 with long setae (2–5x segment length) attached basally; hind femur always darkened, occasionally also fore and mid-femora, and mid- and hind tibiae; gaster concolorous with mesosoma. Relative measurements of antennal segments (length:width): scape, including radicle: (11:3), pedicel: (4:2.5), F1: (4:4), F2: (6:3), F3: (7:3), F4: (8:3), C1: (5:2), C2: (4:2), C3: (4:2). Segments F1 to C1 basally with long setae, about 2–10x widest width of segment. Apex of forewing slightly less truncate than female. Speculum about same size as in female. Gaster length: 30, width: 17. . Genitalia with digitus long and

narrow, length about 6–7x width, tipped with a hook curving laterad; paramere with an apical stylus and slightly shorter than digitus; aedeagus length 11x basal width, about 3x length of digitus, with apex acute.

Distribution. Australia (New South Wales), USA (coastal area of California).

Hosts. Known only from *Trioza eugeniae*, a primary ectoparasitoid of nymphs.

Type material. Holotype ♀: **AUSTRALIA**. NEW SOUTH WALES: 10 km W of Sydney, Ryde School of Horticulture, 20 Nov 1991, D. L. Dahlsten, *Trioza eugeniae* on *Syzygium paniculatum*, Quarantine #91-16.1(ANIC). Paratypes: AUSTRALIA: Same data as holotype, 25 ♀, 13 ♂ (ANIC, BMNH, CAS, USNM, QM, UCD, EMEC, UCR); Ryde, 22 Oct 1994, nymphs of *Trioza eugeniae*, 9 ♀, 7 ♂ (ANIC); QUEENSLAND: Atherton, 2 Aug 1994, Bred from nymph of *Trioza eugeniae*, 1 ♀, 7 ♂ (ANIC); WESTERN AUSTRALIA: Denmark, corner of Hollings Rd and Hwy 1 (South Coast Hwy), 3-6 Oct 2010, D.L. Queiroz & J. La Salle, from *Trioza eugeniae* on *Syzygium paniculatum,* S34°57.588 E117°21.385, 23 ♀, 19 ♂ (ANIC). **USA**. CALIFORNIA. *Alameda Co.*: Albany, UC Gill Tract, 12 Aug 1994, R.L. Zuparko, swept from *S. paniculatum*, 5 ♀ (EMEC); Oakland, 6 Feb 1993, R.L. Zuparko, swept from *S. paniculatum*, 6 ♀, 1 ♂ (EMEC); same location, 15–21 Aug 1993, T. Young, *T. eugeniae* on *S. paniculatum*, 3 ♀, 4 ♂ (EMEC, UCD). *Solano Co*.: Vallejo, 1 Jun 1994, R.L. Zuparko, swept from *Tilia cordata* Miller (Tiliaceae), 2 ♀ (EMEC).



FIGURES 13–16. *Tamarixia dahlsteni*, female. 13. Head, frontal view. 14. Mesosoma, lateral view. 15. Mesosoma, dorsal view. 16. Propodeum.

Etymology. The species is named in honor of the late Dr. Donald L. Dahlsten (University of California, Berkeley), who directed the biological control program against *T. eugeniae* and conducted the foreign exploration which resulted in the discovery and importation of the species.

Discussion. Girault (1915) described *Selitrichodella meteora* and *S. cometes* from Australia. Bouček (1988a) thought both species might belong to *Tamarixia* and reported them as new combinations, noting that the information from the types was not conclusive. The two species are known only from female holotypes that are in poor condition, and in the case of *T. cometes* only by a broken head on a slide. Examination of the types (by RLZ) of the two Girault species (QM) was insufficient to confirm whether either belongs to *Tamarixia*, however, neither is conspecific with *T. dahlsteni*. The antenna of *T. cometes* is entirely yellow, except for a dark spot on the middle of the dorsum of the scape, and another on the dorsum of F1, whereas in *T. dahlsteni* the scape is yellow-brown without darkened areas, and the pedicel and flagellar segments are narrowly darkened basally. In *T. meteora*, the antenna is all yellow and almost the whole dorsum of the gaster is lightened, whereas in *T. dahlsteni* the gaster is lightened only basally.

According to Graham (1991), one of the three apomorphic characteristics of *Tamarixia* is the presence of two pairs of adnotaular setae of the mesoscutum. However, about one quarter of the *T. dahlsteni* specimens examined had 3 setae along either one or both notauli, indicating this is not a reliable character for determining the genus.

Tamarixia dahlsteni has been reported to be the most important natural enemy of *T. eugeniae* in southeast Australia, with the percentage parasitism ranging from 3–62% (Young 2003).

Use of other *Tamarixia* species in biological control

In addition to the two species described above, three species of *Tamarixia* have been used in classical biological control projects:

1. *Tamarixia radiata* (Waterston) against *Diaphorina citri* Kuwayama. The Asian citrus psyllid, *Diaphorina citri*, not only serves as a direct pest of citrus, but can transmit the bacterium which causes citrus greening (huanglungbing). *Tamarixia radiata* has been used on many occasions in biological control projects against *D. citri*. Waterhouse (1998) listed a variety of examples of the use of this parasitoid in Asia, the Pacific and Indian Oceans (see Table 1). More recently *D. citri* has invaded areas of the New World, including Florida, Texas, Mexico, Puerto Rico, Guadeloupe, Brazil and Argentina (McFarland & Hoy 2001; Étienne *et al*. 2001; Michaud 2002; Torres *et al*. 2006; Augier *et al*. 2006; Pluke *et al*. 2008; León & Sétamou 2010). *Tamarixia radiata* has subsequently been released as a biological control agent in many of these countries (McFarland & Hoy 2001; Michaud 2002; Cáceres *et al*. 2005; Torres *et al*. 2006; Lizondo *et al*. 2007; Pluke *et al*. 2008; León & Sétamou 2010). It is showing varying levels of control in different areas; at this point it is not providing effective control in Florida, and further efforts may be necessary to achieve biological control (Qureshi *et al*. 2009).

2. *Tamarixia dryi* (Waterston) against *Trioza erytreae* Del Guercio. The citrus psylla, *T. erytreae*, is an African pest which has invaded offshore islands such as Réunion, Mauritius, Madagascar, as well as Saudi Arabia (Waterhouse 1998). *Tamarixia dryi* has been introduced to both Réunion and Mauritius, where it has proven to be an effective parasitoid. A review of the literature on this parasitoid was provided by van den Berg & Greenland (2000).

3. *Tamarixia leucaenae* Bouček against *Heteropsylla cubana* Crawford. The leucaena psyllid, *Heteropsylla cubana*, attacks several host species, of which the preferred and most important is *Leucaena leucocephala* (Lamarck) (Fabaceae). *Leucaena leucocephala* is native to Central America and Mexico, but has now been introduced throughout the tropics. It is very important for some countries in Africa, because it can survive in arid soils and can be used for various purposes, such as firewood, fiber, animal fodder and recovery of degraded areas. The leucaena psyllid is native to the same area as its host plant. It invaded Hawaii in 1984, and subsequently spread to other Pacific Islands, Southeast Asia, India and Africa (Bouček 1988b; Patil *et al*. 1993; Geiger & Gutierrez 2000). It was recorded from Brazil in 2000 in Espirito Santo, where it was blamed for the decline of *L. leucocephala* plantations. Five years later it was found in Minas Gerais and Parana (Santana *et al*. 2006; Santana & Resende 2008). *Tamarixia leucaenae*, generally in conjunction with an encyrtid parasitoid *Psyllaephagus yaseeni* Noyes, has been introduced into Asia and Africa (Day 1999; Rao *et al*. 2000). Unfortunately, the parasitoids are not proving effective in either Africa (Day 1999) or Asia (Day *et al*. 1995), although there is indication that they may be having greater impact in some parts of Asia (Napompeth 1994).

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